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ABSTRACT

In long established research organizations, it is necessary to safeguard good research ideas originating at lower organizational levels. The upward progress of unusually good ideas in an organizational hierarchy may be compared with that of ordinary ideas by means of a mathematical model, with the assumption that ideas follow a Poisson distribution and Markov random chain walk with an absorption level. Good ideas are novel, synthesizing, simple, aesthetically appealing, problem oriented, and synergistic. The problem of acceptance arises with the interaction of good ideas with the management structure, the good ideas being embedded in a matrix of ordinary ones. Good ideas are more extensively screened than others, having a much lower probability of acceptance at the first review level; they are vetoed so effectively that only one in thirty is ever adopted. Methods for improving the survival probabilities for such ideas include extraofficial documentation, exterior reinforcement, and the bypassing of supervisory cognizance. An organization can become more hospitable to such ideas by reducing the number of levels in the hierarchy and by promoting within the organization on an unselective basis rather than solely on the basis of merit or qualifications. (Mathematical data are included.) (DF)

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THE UPWARD PROGRESS OF UNUSUALLY GOOD IDEAS IN A FOUR-TIER HIERARCHY

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This is intended as an attempt at mathematical modeling of a representative social structure with a view toward increasing the efficiency of the structure. The social structure to be modeled is that of a typical, large, technically-oriented research establishment having a four-tier hierarchical management.

Historically, such research establishments are founded and grow to maturity by acting as a nucleus for the generation and implementation of worthwhile research ideas. As the establishment reaches maturity, however, those individuals responsible for the initial growth leave through normal attrition or are removed and replaced by a group of people who are more oriented toward professional management than creative research. Once replacement occurs, there is a definite range of decline in the long-term quality of the research performed. This decline usually occurs in the face of more stringent hiring practices than were used during the initial growth phase of development, and under rather better overall working conditions than those which existed during the growth period. This anomalous situation is investigated below by means of a highly simplified model in order to establish its causes and to suggest remedies which should serve to make the multilevel research organization more effective.

In the context under study, a particularly relevent feature is the ability, or nonability, of management to direct research. Frequently the managerial role is perceived as managing people who themselves manage research. Since only a minority of unusually good research ideas seemingly are generated by top- or middle-level management personnel, it is imperative that the research staff generate enough unusually good ideas to maintain growth, or at least to support the status quo. Presumably, this postulate is more or less true for most long-established research organizations. As such establishments grow, however, the ratio of trivial jobs to important jobs seems to grow also, and to grow in disproportion to the absolute growth of the establishment. It follows, therefore, that since unusually good ideas will occur in a normal population with some characteristic rate, the problem lies not so much in the fostering of such ideas as in their use after they have occurred. The purpose of this paper is to look briefly at what happens to "good" ideas after they are generated, as they work their way up through a hierarchy, and to compare their fate with "ordinary" research ideas. In order to do this, it will be necessary first to define what is meant by unusually good research ideas as opposed to those research ideas which are more conventional.

Definition: Usually Good Ideas

According to the subjective determination of the authors, an unusually good idea is distinguished from an ordinary idea by one or more of the following features:

(1) The idea is novel in some respect. Classical examples are the assumption that the speed of light is a constant regardless of the frame of reference, or the idea that lunar orbital rendezvous is more feasible than earth orbital rendezvous. Studies of Nobel prize winners, who formulated theories of great social impact, or of people judged by their peers to be unusually creative (Taylor & Barron, 1967; Zukerman, 1968: Deutsch, Platt, & Senghaas, 1971) have shown that the people who generate ideas which are subsequently regarded as outstanding, therefore, meeting most objective criteria of a good idea, are also those who are able to go outside of normal modes of thought for their particular field and use information from other fields of research for their work. As a corollary, good ideas have a second characteristic:

(2) Good ideas synthesize. Classical examples are

(a) The application of orbit theory to the Bohr model of the atom, or

(b) Application of the framework of atomic physics (such as the anharmonic oscillator equation) to orbital theory. Other ideas are the quantization of the gravity field and the application and generalization of electromagnetic and gravity fields to early studies of atomic forces.

In order to be a good synthesizing vehicle, a good idea should have the following characteristics:

(3) Good ideas are simple in essence. While they may be extremely complicated when fully developed, initially, most good ideas are quite simple. Classical examples are to be found in the invention

of the decimal system; the theory of irrational numbers; the notion that meaning is evoked in a receiver, rather than transmitted to him; or, the definition of π in terms of a series expansion. Other examples are Einstein's relation ($E = mc^2$) that a small amount of mass can be converted into a large amount of energy, Avagadro's hypothesis, Newton's laws of motion, or Skinner's S→R model. The simplicity feature leads quite naturally to the next characteristic:

(4) Good ideas are aesthetically appealing. Since the aesthetic qualities of most established theories are more or less self-evident, it will suffice to suggest examples of ideas which have been abandoned largely due to their lack of aesthetic appeal in comparison with an accepted competing theory. Examples which come readily to mind to those associated with a technically-oriented research organization are Routh's equations, virtual work methods of solving mechanics problems, and the Ptolemaic system of astromony. Note that none of these ideas is incorrect. They are all quite correct; their liability is that other methods can be used to solve the same problems more efficiently. Note, in fact, that the matter of "correctness" thus far has not entered into this discussion. A good idea in the present context can be incorrect just as well as correct. The essential point is that a good idea is as correct for its time and place as is possible in the face of factors which are frequently unknown. Copernicus was not correct in the strictest sense; his theory was eventually modified by Kepler. Nor was Newton entirely correct in the light of

subsequent modification by Einstein. Good ideas are satisficing. Thus, a further feature of the good idea can be observed.

(5) Good ideas either (a) resolve existing conflicts, (b) solve existing problems, or (c) point the way to improve future research or the knowledge gained therefrom. A good example is to be found in the reasoning behind the Michelson-Morley experiment which was originally intended to resolve an existing conflict, but which led directly to the special theory of relativity. One additional characteristic of good ideas is now apparent:

(6) Good ideas are synergistic. While conceptual cross-fertilization of ordinary ideas can lead to the generation of an unusually good idea, upon multi-disciplinary examination and scrutiny by many persons, the resulting good idea will generate additional ideas, some of which themselves may be described ultimately as unusually good. The Cartesian coordinate system could not have come about, for example, without Euclidian geometry.

In closing this brief discussion, it is expedient to make a distinction between a good idea and a creative idea. Rube Goldberg's contraptions are exemplary in their creativeness, but no one really thinks of them as good ideas. For present purposes creative ideas are to be taken as those which primarily satisfy criterion (4) above. This distinction is, however, practically meaningless in the present context, since creative people have most of the good ideas (Lloyd, 1966).

In the normal course of events, good ideas as defined and discussed above are developed more or less at random in a Poisson process and

presented along with certain substantiating material to a lower-level manager (usually the immediate supervisor) for approval or disapproval. If approved, this manager then transmits the material upward in the hierarchy to the next higher level. An assumption is made, of course, that these good ideas are embedded in a matrix of more or less ordinary ideas. The problem of acceptance then arises with the interaction of the good ideas with the management structure. Seemingly, in almost all hierarchical structures, lower-level management is not gifted with any particularly magic insight which would facilitate sifting through and sorting out the good ideas from the ordinary ideas. In fact, the situation is likely to be quite the contrary. The manager must make the decision as to the merits of the idea, and however good the idea is, due to (1), it is likely to exist outside of his own field of specialization. In addition, due to (3), at this stage, the idea is not likely to impress the manager as being worth anything at all. Probably, the idea will also meet resistance on account of (4), since the manager is likely to have read, and accepted with some degree of mental effort, someone else's completely developed ideas on the same subject with all the embarrassing loose ends tied down neatly or hidden from sight. In addition, the unusually good idea poses a threat, due to (2), since the manager may well have spent a considerable fraction of his own career mastering a body of technology only to find it now a relatively trivial portion of his much broader scope of work. Thus, the manager, even if he is scrupulously honest, has a vested interest in picking apart any new or novel idea if he can.

The inevitable result is that unusually good ideas not only get reviewed more thoroughly and more harshly than ordinary ideas but also that such intensive screening results in their elimination often because they (or their implications) are, at best, misunderstood or, at worst, not understood at all. The suggestion is made, therefore, that good ideas have a much lower probability of acceptance at the first review level than ordinary ideas.

Moreover, the same process occurs at successively higher levels of review because each reviewer must look at these ideas from a fresh perspective. That is, while higher-level reviewers often exhibit a tendency to accept a lower-level review of an ordinary idea at face value, the novelty of an unusually good idea forces a fresh review at each stage of the management hierarchy. The result, then, is that at each stage of review, each manager critically peruses good ideas independently, usually according to his own biases and personal judgment rather than according to some fixed standard. Thus, good ideas, unlike ordinary ideas, display the Markov property. In addition, by the standards adopted here, the better the idea the more Markov its probability of acceptance will be.

It should be noted that at each stage of review the idea is either vetoed, passed on up the hierarchy to the next higher level, or returned to the orginator for more work. If good ideas are returned to the orginator, they are usually resubmitted at the level from which they were returned

and thus do not have to run the full gamut of review again. This process is equivalent to a delay at that stage of review.

What has been described here can be conceptualized as a stochastic process on an n-step hierarchy with an absorption level where the idea is accepted (Cox and Miller, 1965). While it is conceded that all good ideas do not undergo the same number of reviews, most hierarchies operate within a relatively narrow range of hierarchical levels for any given organizational unit. For purposes of this analysis, it will be assumed that there are four levels of review corresponding to what would normally be considered a large, efficiently run, technically-oriented research establishment. The following description indicates how this process can be modeled.

Absorption Model

Let the number of states starting downward from the absorption level (acceptance of the idea) be numbered beginning at zero and going to a hypothetical bottom rung, as shown schematically below:

Level			Number of People
	0		
	i		N_1
	2		N_2
	3		N_3
	.		.
	.		.
	.		.
	n-1	Immediate supervisor	N_{n-1}
	n	Research worker	N_n

Assume that people are having unusually good ideas at all levels, the basic character of which is a Poisson distribution—the likelihood of success of a single trial becomes smaller as the number of trials increases. That is, the probability of a good idea occurring at any level in time interval Δt is proportional to the product of a factor which expresses the average individual rate of having good ideas λ_i, the length of the time interval Δt, and the number of people N_i doing research at that hierarchy level. Thus, at any level, the probability of formulation of a good idea is given by the statement:

$$\text{Prob } |X_i| = N_i \lambda_i \Delta t$$

Assume that as soon as a good idea is formulated (and no doubt backed up by appropriate, though possibly not complete, evidence) it is passed on to the individual's immediate supervisor. The supervisor acts on the idea after a fixed consideration time, t, and the action takes one of the following forms:

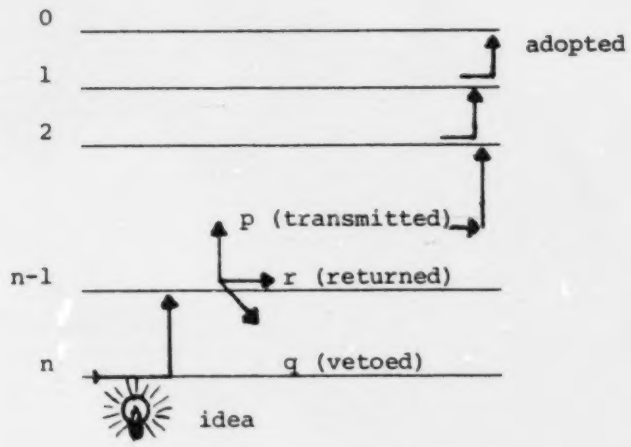
(a) He likes the idea, and so transmits it in turn to his immediate supervisor in the next higher level of the hierarchy. Let the probability of this be p.

(b) He does not like the idea and so vetoes it at this stage. Let this probability be q.

(c) He thinks the idea needs more development and so returns it to the originator or, what is equivalent, sits on it for a period of time. Let this probability be designated by r.

$$p + q + r = 1$$

The process described above thus becomes a random walk taken by the idea after initiation which is illustrated by the following schema:



The state transition matrix for this system is very simple and is given by:

$$[P]_n = \begin{bmatrix} 1 & p_{10} & 0 & 0 & \cdots & 0 \\ 0 & r_{11} & p_{21} & 0 & & \vdots \\ \vdots & & r_{22} & p_{32} & & \vdots \\ \vdots & & & r_{33} & & \vdots \\ \vdots & & & \ddots & & \vdots \\ 0 & & & & r_{n-1,n-1} & p_{n,n-1} \\ 0 & 0 & 0 & 0 & \cdots & r_{n,n} \end{bmatrix}$$

For our special practical example, the following special case applies to a four-tier hierarchy.

$$[P]_4 = \begin{bmatrix} 1 & p_{10} & 0 & 0 & 0 & 0 \\ 0 & r_{11} & p_{21} & 0 & 0 & 0 \\ 0 & 0 & r_{22} & p_{32} & 0 & 0 \\ 0 & 0 & 0 & r_{33} & p_{43} & 0 \\ 0 & 0 & 0 & 0 & r_{44} & p_{54} \\ 0 & 0 & 0 & 0 & 0 & r_{55} \end{bmatrix}$$

In this matrix, for instance, p_{10} is the probability that a manager at level 1 (top management) transmits an idea <u>which came to him from below</u> up to level zero (acceptance). It should be noted that the bottom row is zero except for the last term, i.e., no ideas are transmitted from below to this level. Also, vetoed ideas do not appear since these ideas are removed from the system when vetoed.

It can be seen very quickly, that after k time periods, the state transition matrix which describes the disposition of good ideas is

$$[P]_4^k = \begin{bmatrix} 1 & f_{10} & f_{20} & f_{30} & f_{40} & f_{50} \\ 0 & r_{11} & f_{21} & f_{31} & f_{41} & f_{51} \\ 0 & 0 & r_{22} & f_{32} & f_{42} & f_{52} \\ 0 & 0 & 0 & r_{33} & f_{43} & f_{53} \\ 0 & 0 & 0 & 0 & r_{44} & f_{54} \\ 0 & 0 & 0 & 0 & 0 & r_{55} \end{bmatrix}$$

For instance, after four steps

$$[P]_4^4 = \begin{bmatrix} 1 & A_4 & B_4 & C_4 & D_4 & P_4 \\ 0 & r_{11}^4 & E_4 & F_4 & G_4 & H_4 \\ 0 & 0 & r_{22}^4 & I_4 & J_4 & K_4 \\ 0 & 0 & 0 & r_{33}^4 & L_4 & M_4 \\ 0 & 0 & 0 & 0 & r_{44}^4 & N_4 \\ 0 & 0 & 0 & 0 & 0 & r_{55}^4 \end{bmatrix}$$

where the symbol 0 always represents zero and where

$$A_4 = p_{10}\left(1 + r_{11} + r_{11}^2 + r_{11}^3\right)$$

$$B_4 = p_{10}p_{21}\left(1 + r_{11}^2 + r_{22}^2 + r_{11} + r_{22} + r_{11}r_{22}\right)$$

$$C_4 = p_{10}p_{21}p_{32}\left(1 + r_{11} + r_{22} + r_{33}\right)$$

$$D_r = p_{10}p_{21}p_{32}p_{43}$$

$$P_3 = 0$$

$$E_4 = p_{21}\left(r_{11}^3 + r_{11}^2 r_{22} + r_{11}r_{22}^2 + r_{22}^3\right)$$

$$F_4 = p_{21}p_{32}\left(r_{11}^2 + r_{22}^2 + r_{33}^2 + r_{11}r_{22} + r_{11}r_{33} + r_{22}r_{33}\right)$$

$$G_4 = p_{21}p_{32}p_{43}\left(r_{11} + r_{22} + r_{33} + r_{44}\right)$$

$$H_4 = p_{21}p_{32}p_{43}p_{54}$$

$$I_4 = p_{32}\left(r_{22}^3 + r_{22}^2 r_{33} + r_{22}r_{33}^2 + r_{33}^3\right)$$

$$J_4 = p_{32}p_{43}\left(r_{22}^2 + r_{33}^2 + r_{44}^2 + r_{22}r_{33} + r_{22}r_{44} + r_{33}r_{44}\right)$$

$$K_4 = p_{32}p_{43}p_{54}\left(r_{22} + r_{33} + r_{44} + r_{55}\right)$$

$$L_4 = p_{43}\left(r_{33}^3 + r_{33}^2 r_{44} + r_{33}r_{44}^2 + r_{44}^3\right)$$

$$M_4 = p_{43}p_{54}\left(r_{33}^2 + r_{44}^2 + r_{55}^2 + r_{33}r_{44} + r_{33}r_{55} + r_{44}r_{55}\right)$$

$$N_4 = p_{54}\left(r_{44}^3 + r_{44}^2 r_{55} + r_{44}r_{55}^2 + r_{55}^3\right)$$

The states along the first row show the probability of acceptance after four time intervals for good ideas originating at the various hierarchy levels. For instance, P_4 is the probability that a good idea which originiated at the bottom, and hence was first passed on by a supervisor at level 4, has been accepted; A_4 is the probability that an idea originating at level 2 and hence acted on by level 1 has been accepted, etc.

The above procedure could be carried out analytically to find the equilibrium distribution. Since equilibrium is reached rather quickly in this simple system, however, it is more to the point to show numerical results. The following values are representative of $[P]^k$ for various values of k when it is assumed $p = r = \frac{1}{2}$ and $q = 0$. That is, acceptance and revision are equally likely, but no ideas are rejected.

$$[P]_4^1 = \begin{bmatrix} 1.000 & .500 & .000 & .000 & .000 & .000 \\ .000 & .500 & .500 & .000 & .000 & .000 \\ .000 & .000 & .500 & .500 & .000 & .000 \\ .000 & .000 & .000 & .500 & .500 & .000 \\ .000 & .000 & .000 & .000 & .500 & .500 \\ .000 & .000 & .000 & .000 & .000 & .500 \end{bmatrix}$$

$$[P]_4^4 = \begin{bmatrix} 1.000 & .937 & .678 & .312 & .062 & .000 \\ .000 & .062 & .250 & .375 & .250 & .062 \\ .000 & .000 & .062 & .250 & .375 & .250 \\ .000 & .000 & .000 & .062 & .250 & .375 \\ .000 & .000 & .000 & .000 & .062 & .250 \\ .000 & .000 & .000 & .000 & .000 & .062 \end{bmatrix}$$

$$[P]_4^5 = \begin{bmatrix} 1.000 & .968 & .812 & .500 & .187 & .031 \\ .000 & .031 & .156 & .312 & .312 & .156 \\ .000 & .000 & .031 & .156 & .312 & .312 \\ .000 & .000 & .000 & .031 & .156 & .312 \\ .000 & .000 & .000 & .000 & .031 & .156 \\ .000 & .000 & .000 & .000 & .000 & .031 \end{bmatrix}$$

$$[P]_4^{10} = \begin{bmatrix} 1.000 & .999 & .989 & .945 & .828 & .623 \\ .000 & .000 & .009 & .043 & .117 & .205 \\ .000 & .000 & .000 & .009 & .043 & .117 \\ .000 & .000 & .000 & .000 & .009 & .043 \\ .000 & .000 & .000 & .000 & .000 & .009 \\ .000 & .000 & .000 & .000 & .000 & .000 \end{bmatrix}$$

There are several interesting conclusions that can be drawn from this numerical example. First, in a hierarchy with no rejection, all ideas ultimately become accepted but ideas which originate with top management or slightly below become accepted with much greater frequency than those generated at the lower levels. The implications for the individual researcher are clear. Lower level personnel must spend more time revising their work in order to anticipate and meet objections from higher levels, than must higher-level personnel.

The most important conclusions, however, are to be drawn from a representative state transition matrix which allows for ideas to be vetoed. The following is a selection of representative results for a situation where $p = q = r = \frac{1}{3}$. That is, acceptance, rejection, and revision are equally likely.

$$[P]_4^1 = \begin{bmatrix} 1.000 & .333 & .000 & .000 & .000 & .000 \\ .000 & .333 & .333 & .000 & .000 & .000 \\ .000 & .000 & .333 & .333 & .000 & .000 \\ .000 & .000 & .000 & .333 & .333 & .000 \\ .000 & .000 & .000 & .000 & .333 & .333 \\ .000 & .000 & .000 & .000 & .000 & .333 \end{bmatrix}$$

$$[P]_4^4 = \begin{bmatrix} 1.000 & .493 & .222 & .074 & .012 & .000 \\ .000 & .012 & .049 & .074 & .049 & .012 \\ .000 & .000 & .012 & .049 & .074 & .049 \\ .000 & .000 & .000 & .012 & .049 & .074 \\ .000 & .000 & .000 & .000 & .012 & .049 \\ .000 & .000 & .000 & .000 & .000 & .012 \end{bmatrix}$$

$$[P]_4^5 = \begin{bmatrix} 1.000 & .497 & .238 & .098 & .028 & .004 \\ .000 & .004 & .020 & .041 & .041 & .020 \\ .000 & .000 & .004 & .020 & .041 & .041 \\ .000 & .000 & .000 & .004 & .020 & .041 \\ .000 & .000 & .000 & .000 & .004 & .020 \\ .000 & .000 & .000 & .000 & .000 & .004 \end{bmatrix}$$

$$[P]_4^{10} = \begin{bmatrix} 1.000 & .499 & .249 & .124 & .061 & .028 \\ .000 & .000 & .000 & .000 & .002 & .003 \\ .000 & .000 & .000 & .000 & .000 & .002 \\ .000 & .000 & .000 & .000 & .000 & .000 \\ .000 & .000 & .000 & .000 & .000 & .000 \\ .000 & .000 & .000 & .000 & .000 & .000 \end{bmatrix}$$

Although complete data are not presented here, one finds that by the tenth time interval almost all ideas in this hierarchy have been either accepted or rejected so that $[P]^{10}$ represents a good summary picture. With this system only 2.8 percent or roughly one unusually good idea in thirty actually is shown to have been accepted. It should be pointed out that this is a feature of the hierarchy and the probabilities selected and is not necessarily a function of how good the ideas are. Although it is admitted that some good ideas are

obvious to all, it is suggested that this matrix is probably the most realistic model for unusually good ideas.

In order to be realistic, this matrix should be compared with one which would be more applicable to ordinary research ideas. These ideas are characterized by a relatively thorough review by the first reviewer but are likely to be accepted much more readily by the higher management levels, the assumption being that the immediate supervisor is competent to review the work and that higher supervisory levels would function in the present context in a "rubber stamp" capacity. Thus the probability of passing an idea on up the hierarchy is enhanced for these steps while the probability of an idea being vetoed or revised is correspondingly reduced. The matrices shown are for a four-tier hierarchy which has $p = r = \frac{1}{3}$ at the first supervisor level, but $p = 0.90$, $q = 0.05$, and $r = 0.05$ at the higher levels.

$$[P]_4^1 = \begin{bmatrix} 1.000 & .900 & .000 & .000 & .000 & .000 \\ .000 & .050 & .900 & .000 & .000 & .000 \\ .000 & .000 & .050 & .900 & .000 & .000 \\ .000 & .000 & .000 & .050 & .900 & .000 \\ .000 & .000 & .000 & .000 & .050 & .333 \\ .000 & .000 & .000 & .000 & .000 & .333 \end{bmatrix}$$

$$[P]_4^4 = \begin{bmatrix} 1.000 & .947 & .897 & .838 & .656 & .000 \\ .000 & .000 & .000 & .012 & .145 & .242 \\ .000 & .000 & .000 & .000 & .012 & .130 \\ .000 & .000 & .000 & .000 & .000 & .045 \\ .000 & .000 & .000 & .000 & .000 & .014 \\ .000 & .000 & .000 & .000 & .000 & .012 \end{bmatrix}$$

$$[P]_4^5 = \begin{bmatrix} 1.000 & .947 & .897 & .849 & .787 & .218 \\ .000 & .000 & .000 & .001 & .018 & .129 \\ .000 & .000 & .000 & .000 & .001 & .047 \\ .000 & .000 & .000 & .000 & .000 & .015 \\ .000 & .000 & .000 & .000 & .000 & .004 \\ .000 & .000 & .000 & .000 & .000 & .004 \end{bmatrix}$$

$$[P]_4^{10} = \begin{bmatrix} 1.000 & .947 & .897 & .850 & .805 & .401 \\ .000 & .000 & .000 & .000 & .000 & .000 \\ .000 & .000 & .000 & .000 & .000 & .000 \\ .000 & .000 & .000 & .000 & .000 & .000 \\ .000 & .000 & .000 & .000 & .000 & .000 \\ .000 & .000 & .000 & .000 & .000 & .000 \end{bmatrix}$$

It can be seen, by comparing this ordinary research idea matrix with the unusually good idea matrix at step 10, just how devastatingly effective a hierarchy is in repressing good research ideas.

As a matter of completeness, the probability functions and probability density functions for ideas originating at the lowest level are presented in Figures 1 and 2. The particularly significant conclusions to be drawn from these figures are that the distributions are Maxwellian in nature with a built-in delay before the first idea can reach the acceptance level and that it does not pay in the case of unusually good ideas to revise the idea more than three or four times since the probability of acceptance is not significantly improved with subsequent iterations.

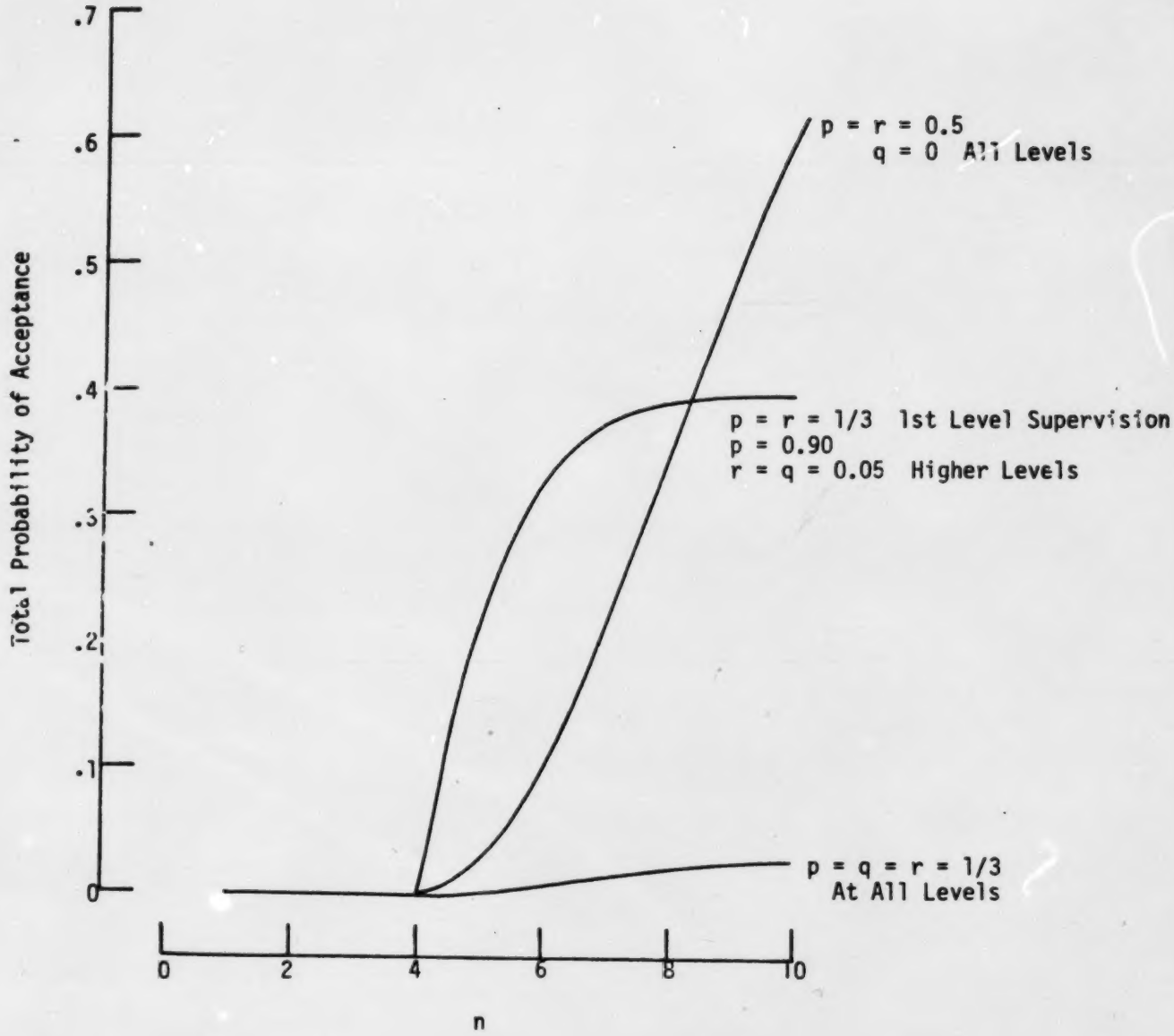
Management Implications

While the state transition matrix describes what happens to the individual ideas once formed, it is probably more important to know what the total effect is on a technically-oriented research establishment. The total number of unusually good ideas in a given hierarchy level depends on the number of people in that level and on their individual rates of idea generation. The total number of good ideas at any level at any given time depends on the number of good ideas which have reached that level from below as well as on the number of good ideas formulated at that level. Thus, the total matrix can be represented by:

$$[\pi] = \begin{bmatrix} \pi_0^k \\ \pi_1^k \\ \vdots \\ \pi_5^k \end{bmatrix}$$

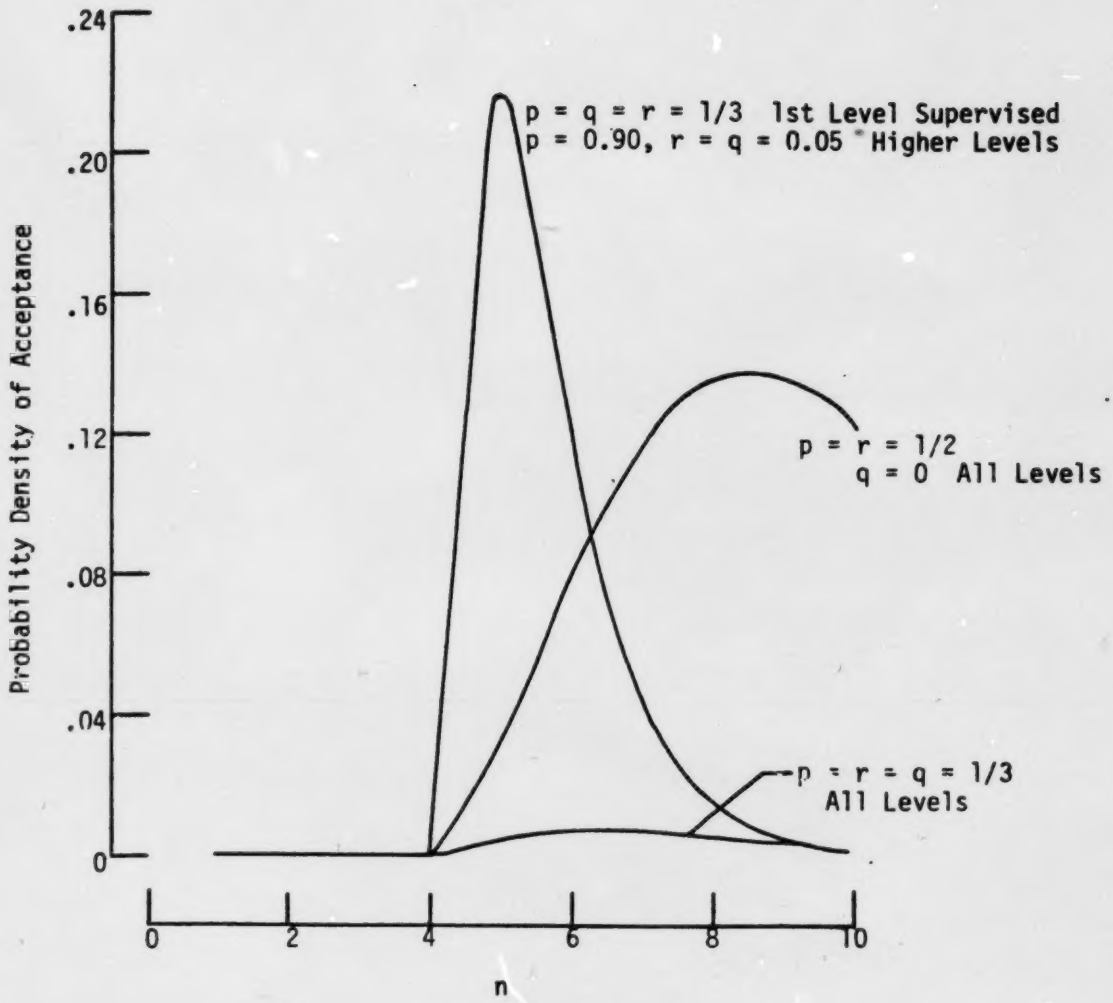
$$\begin{bmatrix} \pi_0^k \\ \pi_1^k \\ \pi_2^k \\ \pi_3^k \\ \pi_4^k \\ \pi_5^k \end{bmatrix} = \begin{bmatrix} 1 & f_{10} & f_{20} & f_{30} & f_{40} & f_{50} \\ 0 & r_{11}^k & f_{21} & f_{31} & f_{41} & f_{51} \\ 0 & 0 & r_{22}^k & f_{32} & f_{42} & f_{52} \\ 0 & 0 & 0 & r_{33}^k & f_{43} & f_{53} \\ 0 & 0 & 0 & 0 & r_{44}^k & f_{54} \\ 0 & 0 & 0 & 0 & 0 & r_{55} \end{bmatrix} \begin{bmatrix} N_1\lambda_1 \Delta t \\ N_2\lambda_2 \Delta t \\ N_3\lambda_3 \Delta t \\ N_4\lambda_4 \Delta t \\ N_5\lambda_5 \Delta t \\ N_6\lambda_6 \Delta t \end{bmatrix}$$

Since, in a normal hierarchy, $N_1 < N_2 < \ldots N_n$, it can be seen that decreasing the numbers of people at the higher levels of the hierarchy tends to restore a balance to some degree. For instance, in the four-tier hypothetical case illustrated previously, just one step below the top review level one individual is about eight times as effective as the same individual at the bottom level. It also tends to be true that λ_i is different at different levels of a hierarchy due to promotion selection procedures, and the mix of time spent in actually doing research as opposed to time involved with managerial or other duties.



Probability Versus Number of Time Intervals for Three Sets of Stochastic Matrix Assumptions on a Four-Tier Hierarchy.

Figure 1



Probability Density Versus Number of Time Intervals for Three Sets of Stochastic Matrix Assumptions on a Four-Tier Hierarchy.

Figure 2

Techniques of Acceptance Enchancement

From the foregoing it can be seen that the odds of getting an unusually good research proposal adopted are indeed small if the formal organizational structure is followed when transmitting the idea upward. Although most researchers gradually become aware of this predicament, most are not aware of the extreme effectiveness of the phenomenon. In the course of the development and growth of a technically-oriented research establishment successful people ususally find ways of circumventing the formal system. Their techniques fall into three basic categories, referred to as:

(1) Extraofficial Documentation (Bootlegging).

(2) Exterior Reinforcement (The Outside Expert Gambit).

(3) Transcendence of Supervisory Cognizance (Going over the Boss's Head).

Only a brief discussion is called for in the first case. The technique consists chiefly of converting the unusually good idea into what is, in effect, an ordinary idea, thus in its chameleon-like state, enhancing its probability of acceptance. This is usually accomplished by performing the appropriate research with money and equipment originally designated for some other activity, enabling the good idea to be parasitic, and then presenting the accomplished fact to the hierarchy. Even if done on a modest scale, it sometimes suffices to convince others of the soundness of the idea. After acceptance, research already performed clandestinely is repeated openly with a very high probability of success.

In all successful research establishments, at least some extraofficial documentation is tolerated since it seems to be necessary for survival in an environment of changing external circumstances. The reason for this flexibility is presumably that institutions where this type of activity is not tolerated become extinct in a short period of time due to a lack of adaptability. As a corollary, wise administrators often find it expedient not to notice such activity so long as it seems harmless, does not cost too much money, and does not interfere with ongoing funded research.

This technique however, has several drawbacks. First, if a substantial number of people are to be involved, success depends upon the persuasive ability of one or more of the interested parties. That is, this method depends on knowing the right people. Moreover, the work must be of such a nature that it can be hidden reasonably well so as to minimize the chance of "premature" discovery. Lack of discovery depends upon having an appropriately low ratio of management personnel to research staff, so that supervision is not too strict, i.e., a relatively flat organizational structure.

This kind of research is usually carried on with a limited amount of funds and frequently with equipment that is less than the best. Thus, the chances of success are severely prejudiced. Also, when large amounts of money are necessary the chance of success depends on the audacity of the individual experimenter. Since the chances of failure in good research are always high, consideration must be given to the possibility of failure and the subsequent necessity of disposing of the hardware. In the practical domain, personal experience indicates that it is difficult to bury a special piece of apparatus if it is more than two-

and-a-half feet in diameter! This seems to put some limit on the size of these projects.

When the research requirements demand the services of a large number of people, extraofficial documentation frequently gets low priority so that the time scale for such clandestine research is excessively long.

It would seem, then, that the best conditions for extraofficial documentation activity are in the theoretical domain where projects are not so readily watched and where disguising the real nature of the research is easiest. For instance, extra FORTRAN statements in a normally legitimate computer program are hardly ever noticed; excess computer cards can be disposed of by using them as note paper.

The method of exterior reinforcement consists of giving a paper before an audience of outsiders in the hope that ideas will be stolen, refined, and then returned to the hierarchy. Since outside experts are frequently regarded in awe by high-level management, these ideas are sometimes given a less critical review than would be the case for the same ideas generated internally. Hence, the chance of acceptance is much higher. This technique in its most naive state depends on being lucky enough to have an interested outside researcher willing to appropriate ideas. If found to be practical, connivance can substantially enhance a good idea's chances of success.

There are several drawbacks to this technique. First, original authorship is usually lost. Second, it sometimes takes strenuous effort and years of debate before any substantial results can be realized. The method works best for very large or diffuse ideas where a whole segment of community opinion can be mobilized and/or where the

synergistic properties of the idea are clearly evident. Unusually good ideas propounded in this manner frequently are lost in an even larger matrix of ordinary ideas. This is especially true for ideas put forth in trade journals and professional societies due to the prevalent practice of salvaging some good out of rejected contract proposals by publishing the results. Finally, this technique implicitly presupposes at least some level of acceptance within a hierarchy since editorial review is usually a prerequisite to outside publication.

The third method of getting important research ideas accepted, transcendence of supervisory cognizance (bypassing), is more frequently used and is, by and large, the most successful. This seems to be the only way in which really important research can be put through, and it would seem fair to say that no really big project initiated at the lower levels of a hierarchy has ever been successful without employment of this tactic. The mechanics of bypassing become obvious on examination of the other columns in the transition state matrices. It can be seen that the probability of success goes up spectacularly each time a reviewer can be eliminated from the chain of review. It can also be seen that, while a four-tier hierarchy suppresses practically all good ideas, those same ideas inserted in a two-tier hierarchy have quite reasonable odds of success. While care should be used in interpreting these tables (each higher member of the hierarchy reviews ideas originating below his own level) the indication supports practical experience. For instance, the matrix shows why supervisors tend to receive more awards than is statistically probable based on their numbers. What is suggested is that supervisors tend to get more of their own good ideas through the hierarchy, not that they are noticeably more productive

as a group.

The successful use of the technique of transcendence of supervisory cognizance in a successful hierarchy depends on several factors. First, and most important, there must be some receptive and influential individual higher up in the hierarchy than one's immediate supervisor. It also follows that the higher up the receptive individual is placed, the better the chances of ultimate success. The probability of success increases dramatically if several organizational levels can be bypassed. Success of this technique also depends to a certain extent on the existence of some form of restraint on retaliation by supervisors. The unsuccessful, or partially successful, use of this method frequently results in slower raises, or no raises at all for the individual (Taylor and Barron, 1963; Lloyd, 1967). What is more important, however, is that the belief must exist that retaliation, direct or indirect, will not be employed. While this might seem like belaboring the obvious, experience indicates that many research workers do predicate their actions on this assumption. In summary, this technique can only be effective if informal upward communication lines are left open, and if such use of them as described here is encouraged.

Implications for Hierarchical Management

Up to this point, this study has been confined to considerations of ideas as they traverse the various levels of the hierarchy. It has been stressed particularly that the concept of a good idea is to be held as a mathematical entity on its own, and that such an idea is characterized by its transition probability on an n-state probability transition matrix. It should be obvious, however, that there is a considerable similarity

between unusually good research ideas and creative ideas. In particular, it would seem that people who have good ideas are probably, in most cases, creative people. The authors continue to make this distinction; however, since unusually good ideas as such are relatively little studied in the literature, it will be necessary in what follows to make liberal use of selected literature based on creativity studies. It will be assumed that a substantial fraction of the people whom it has been convenient, so far, to designate as receptive are also creative, although this is not always the case. It will also be assumed that these people, generally, possess essentially the same personal character traits as creative people. These character traits may vary somewhat between professions, but are sometimes well characterized within the profession (e.g., in the form of a stereotype).

The creative research worker in the physical sciences has been studied extensively by Taylor and Barron (1963) and others, and some of his characteristics are as follows:

(1) He is essentially introverted and inner directed.

(2) He is deeply committed to his field of research.

(3) He thrives on complexity, and his mind is so constructed that he likes to bring order out of chaos. He is the kind of person who concentrates on the similarities in dissimilar things, rather than one who notices the difference.

(4) His undergraduate grade average is not a valid indicator of anything.

In addition, post facto studies of Nobel prize winners (Gray, 1949; Lloyd, 1966), revealed that a lower cutoff point seems to exist at about I.Q. 130, but that above this point, there is no particular correlation of intelligence to creative output. Moreover, there is some evidence (Taylor and Barron, 1963), to the effect that creative people have negative promotion potential in organizations. (Perhaps these people become external consultants.)

If these same generalizations apply to receptive people in a hierarchy -- and this is, of course, very tentative -- they suggest some rather dismal conclusions:

(1) Hierarchies tend to promote nonreceptive people to management positions.

(2) The more selective the promotion procedure is (i.e., promotion according to perceived merit), the more effective this screening-out process will be.

These phenomena can be explained in an ad hoc manner if one examines the time scales involved. It seems reasonable to assume that in a technically-oriented research organization the time scale between the conception of an unusually good idea and the fruition of it in terms of tangible results is between 5 and 15 years. Management promotions, on the other hand, are usually based on recent performance over periods of 5 years or less. It thus follows that if receptive individuals in a hierarchy are the same people in later life who, earlier in life, were producing good ideas, i.e., "It takes one to know one" (Zukerman, 1967) in all probability, receptiveness has not been the principal consideration in establishing their place in the hierarchy. If true, promotion on an

unselective basis (such as seniority or consanguinity) is probably a more effective management procedure than promotion on the basis of merit in order to insure the placement of receptive individuals within the hierarchy.

Conclusions

If the foregoing analysis is even partially correct, some definite conclusions can be drawn as to how management can improve research efficiency.

(1) The number of levels in the hierarchy should be reduced to the minimum possible number consistent with proper evaluation and review. Note that the number of hierarchical levels in an organization is not necessarily the same as, and may be independent from, the number of levels a good idea must traverse as it moves upward. It would seem that two appraisals by competent reviewers should be sufficient to insure technical correctness to within the present state of the art. A final review at the highest level before the allocation of large amounts of money is obviously also necessary since several unusually good ideas may be in competition at that level. Thus, the most effective organizations are probably organized as a three-tier hierarchy.

(2) Employees should be encouraged to submit their more novel ideas contrary to much present practice. The most imaginative ideas often lead to those with the most utility.

(3) It should be made mandatory that all ideas submitted in writing be evaluated and forwarded with or without comment to the next higher step in the hierarchy (a positive application of the one-plus-one system so frequently used to handle complaints or to conduct performance

appraisals). Review at the lowest level should be limited to one person, either the supervisor or his designee, but never both. Reviews at subsequent levels should be by the initial reviewer's supervisor or his designee. It should be recognized that a short initial submission at the next higher level might be necessary in order to keep the work load down.

(4) Once the second-level review has occurred, idea appraisal should be prompt and idea-specific. The initiator of the idea should be informed of its status. Feedback about his idea should be responsive (Redding, 1966; 1972).

(5) Other channels should be left open deliberately for the submission of ideas. Suggestion forms do not seem to fill this need in practice.

(6) A deliberate effort should be made to find receptive individuals and to promote these people to strategic positions within the hierarchy. In fact, such people certainly exist in successful hierarchies at any given time, but more people and more ready accessibility are key points to keep in mind here.

(7) Most promotions should be made principally on the basis of seniority or consanguinity, perhaps from a selected list to rule out downright incompetents and to insure inclusion of those who are truly innovative. In no case should such a list contain less than three quarters of the available personnel. This should be done in order to make sure of promoting receptive people into the management structure. Merit should be apportioned into the promotion formula, however.

(8) Supervisory bypassing should be encouraged within the context of ideation and respected by top-level management, not discouraged.

(9) High-level technical positions should be filled by technical people. This is not to say that people trained in management disciplines should be excluded but that a supervisor's training, whether formal or experiential should be both technical and managerial (Drucker, 1974).

(10) Research papers, personal research notes, and research communications should get priority over purely managerial paperwork.

(11) Extraofficial documentation within reasonable limits should be encouraged.

(12) The existence of a disproportionate number of awards or recognition for low level managers should be interpreted as a sign that there are too many managers in the hierarchical structure in relation to the number of research workers, or that too many unusually good ideas are being appropriated overtly or covertly by higher-level managers.

Implications for the Individual Research Worker

In addition to the foregoing structural conclusions which apply to hierarchy management procedures, the individual research worker should be guided by several principles of behavior.

(1) The individual worker should submit his best research proposals at the highest possible hierarchy level and should be prepared to go to higher levels if the ideas are rejected for what is insufficient cause in his judgment.

(2) It does not pay for the individual researcher to resubmit proposals more than three or, at most, four times at the same hierarchy rung. After that, the ideas should be abandoned, carried to a level higher than the one at which it was rejected, or reworked by exterior reinforcement (if such effort is justified).

(3) The effective research worker should be prepared to have his better ideas rejected, and should not be easily discouraged to the point where his idea-submitting behavior is extinguished. Success is a matter of playing at unfavorable odds often enough to win occasionally.

Nontechnical Hierarchies

Although the main body of this analysis is oriented toward the subject of strictly technical hierarchies, it is instructive in this context to look briefly at some of the more successful, therefore stable, historical hierarchial systems. There are several nonscientific hierarchies of interest in this regard. In terms of general categories, they are:

Religious Hierarchies

Monarchies

Military Hierarchies

Business and Industrial Organizations (especially older ones)

The Civil Service

Colleges and Universities

The reason for the long-term stability of these systems is quite possible that they do, in fact, promote receptive individuals to top management levels. A notable characteristic of these systems is that management people seem to be promoted by two main methods, seniority and

birthright. It should be noted that both methods are essentially random. A particularly interesting case is that of the monarchies, since here the method of promotion is predominately genetic. At first glance, it seems puzzling that such a system, which is widely regarded as faulty today, should have remained as stable as it has throughout history. This system has been documented from a genetic standpoint fairly thoroughly by Darlington (1969), and it would seem that, provided the right genetic variability is present, the system has reasonably good survival potential.

Systems in which promotion is based primarily on merit would seem to work best when the hierarchies are in the process of rapid expansion. That is, when due to outside pressures and limitations on the amount of time available for the selection of managers, the selection is most casual and the standards of acceptance, the lowest. The applicability of the Peter Principle to hierarchies of this type has been reported (Kane, 1970), and his results are consistent with this conclusion; namely, that the Peter Principle does not apply as completely to rapidly growing hierarchies as to those growing slowly.

A notable example of the rapid growth success syndrome is to be seen by examining the post World War II business growth of Japan, which is a two-level system with promotion at the top level based almost exclusively on seniority. This system has been highly successful in competition with supposedly much more "modern" methods used by businesses in the West.

Summary

An investigation of the probability of unusually good research ideas being accepted in a four-tier research hierarchy has been made on the assumption that these ideas are Poisson-distributed and reviewed in a manner characteristic of a Markov chain random walk with an absorption level. The conclusion was reached that unusually good ideas are vetoed so effectively that only one good idea in thirty is ever actually adopted through the hierarchy. Methods of improving the odds were discussed and it was concluded that extraofficial documentation and exterior reinforcement are somewhat effective, but that transcendence of supervisory cognizance (bypassing) is the most effective means available. In addition, methods for improving the effectiveness of the hierarchy were considered and it was suggested that reducing the number of levels in the hierarchy is effective. It was also proposed that promotion on an unselective basis, such as seniority or consanguinity, is probably an effective management procedure as compared to promotion solely on the basis of merit or qualification.

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